Modeling the migration of trace elements from tailings towards aquifers

Salma Kahlaoui, Vincent Cloutier, Eric Rosa
Groundwater Research Group, Université du Québec en Abitibi-Témiscamingue

Summary

This study focuses on the modeling of trace elements transport from mine tailings towards a local groundwater flow system located nearby a municipal water intake. The study site corresponds to the Quémont-2 tailing pond, a property of Glencore Canada Corporation - Fonderie Horne (GCC-FH), in Rouyn-Noranda, Quebec, Canada. The tailing pond is located 2,5 km SE of Lake Dufault, which is the main surface water intake for the city of Rouyn-Noranda (WSP, 2019). A total of 13 samples were collected in 2019 in order to evaluate water quality within the tailing pond and surrounding aquifers. The analyses included major and trace elements along with stables isotopes of the water molecule (δ^2H-δ^{18}O), chlorine (δ^{37}Cl) and bromine (δ^{81}Br). These data are used jointly with pre-existing environmental studies for constructing 2D groundwater flow and transport models using SEEP/W and CTRAN/W. The simulations will ultimately be used for evaluating and optimizing reclamation plans (MERN et MELCC, 2017).

Background and objectives

The release of metals from active mining sites towards natural freshwaters is increasingly documented in the technical and scientific literature. Among other aspects, systematic monitoring procedures are prescribed by law for ensuring that the mine effluents released to the environment respect strict criteria related to dissolved species concentrations and toxicity. Such monitoring allows for reducing the impacts on the quality of natural waters downstream of the point specific discharge of mine effluents. Nevertheless, quantifying the diffuse pollution associated with the fluxes of dissolved species from mine tailings towards the surrounding aquifers remains challenging. While observation wells, piezometers, boreholes and lysimeters can provide information on the concentration [ML^{-3}] of different dissolved species in groundwater, the fluxes [$ML^{-3}T^{-1}$] transported by groundwater are rarely precisely evaluated. One of the main limitations is that field monitoring data generally provide local observations that do not allow for a straightforward quantification of advection, dispersion, diffusion, sorption and precipitation-dissolution processes along groundwater flowpaths. Coupled hydrogeological and geochemical models stand as potential tools for addressing this issue. Fitting in this context, the present study focuses on the development of a groundwater flow and mass transport model coupled to geochemical modeling for documenting the fluxes of trace elements from a tailing pond towards surrounding bedrock aquifers. Groundwater flow and mass transport are simulated using SEEP/W and CTRAN/W while saturation indices along flowpaths are calculated using PHREEQC. The focus is set on the Quémont-2 site, a property of Glencore Fonderie Horne located in Rouyn-Noranda, Quebec, Canada (Figure 1).

Figure 1 Localisation of the Quémont-2 site and sampled wells

Methods

A seasonal monitoring program was initiated in fall 2019 for documenting groundwater geochemistry in observation wells completed in the tailing pond (n = 2), within till deposits (n = 1) and within the bedrock (n = 10) (Figure 1). The targeted wells are ~5 cm in diameter and their depths range from 7,3 m to 42,795 m. During the fall 2019 sampling campaign, groundwater wells were flushed of one time their volume using a low flow procedure (CEAEQ, 2008; US EPA, 1996) and *in situ* parameters (Temperature, pH, redox potential (OPR), dissolved oxygen (DO), electrical conductivity (EC)) were subsequently measured at five minute intervals using a *YSI 556 Professional Plus* multi-parameter probe. Groundwater samples were collected once stable values were obtained for three consecutive readings. Samples were filtered on site at 0,45 µm, immediately after collection. Samples storage and conservation was done following the standard procedures of the Quebec Ministry of the Environment. The samples were analyzed at a laboratory that is accredited by the Quebec Ministry of the Environment. The analytical program included anions (Br, Cl, F, NO_2, NO_3, SO_4), ammonia nitrogen, inorganic

phosphorus, dissolved organic carbon, trace metals and total alkalinity. Samples were analysed for stables isotopes of the water molecule (δ^2H-$\delta^{18}O$), and some samples were also analysed for chlorine ($\delta^{37}Cl$) and bromine ($\delta^{81}Br$). Another field sampling campaign is planned for August 2020.

The available data are used for modeling groundwater flow and mass transport along a 2D cross-section extending from the tailing pond to the shoreline of Lake Dufault. The model is constructed using SEEP/W and CTRAN/W. The geometry of the SEEP/W model is based on the data from pre-existing environmental assessment studies conducted at the study site. A constant head boundary condition is applied for representing Lake Dufault, while no-flow boundary conditions are applied at the water divide and within the bedrock, at a depth of 75 m. Local meteorological data are used for defining a land-climate surface boundary condition. Groundwater heads measured in observation wells are used for calibrating the groundwater flow model. The CTRAN/W model uses the steady state groundwater flows simulated using SEEP/W as a parent analysis. The model is first used to simulate the transport of conservative and non-conservative dissolved species from the tailings towards the bedrock aquifer. The available chemical and isotopic analyses are used for calibration. Saturation indexes are calculated using PHREQC in order to document the potential effect of precipitation-dissolution along flowpaths.

Preliminary results and Discussion

The measured pH values ranged between 5.61 in well Q2-R-PO-04-18 and 11.61 in well Q2-R-PO-05-18. Overall, the electrical conductivity of water is higher in the tailings, although a value 5184 µS/cm was detected in well Q2-R-PO-02-18, which is located in bedrock. The measured ORP values allow for calculating Eh values ranging between 133,219 mv in well Q2-R-PO-01-18 and 494.475 mv in well PO-Q2-18-07. The significant variations measured in these *in situ* parameters highlight the need of evaluating saturation indices for better interpreting simulations of advection-dispersion-diffusion-sorption processes conducted using SEEP/W and CTRAN/W. The piper diagram interpreted from the first results shows great heterogeneity in water types with three dominant water types: Ca-HCO$_3$ (Group 1), Ca-SO$_4$ (Group 2) and Na-SO$_4$ (Group 3) (Figure 2). The concentrations of major and trace elements measured in groundwater from the sampling wells were compared to groundwater criteria for resurgence in surface water as established by the Quebec Ministry of the Environment (MELCC, 2019). Figure 3 shows the measured exceedances of comparison criteria for the analysed parameters. The ongoing work consists in calibrating the SEEP/W and CTRAN/W models in order to document the transport mechanisms that are likely to control the migration of trace elements towards the bedrock aquifers. This step of the research project is still at a start-up stage.
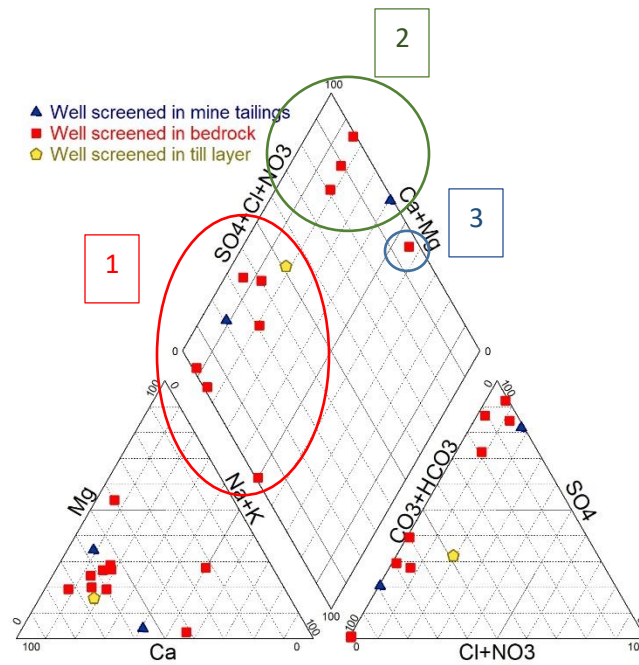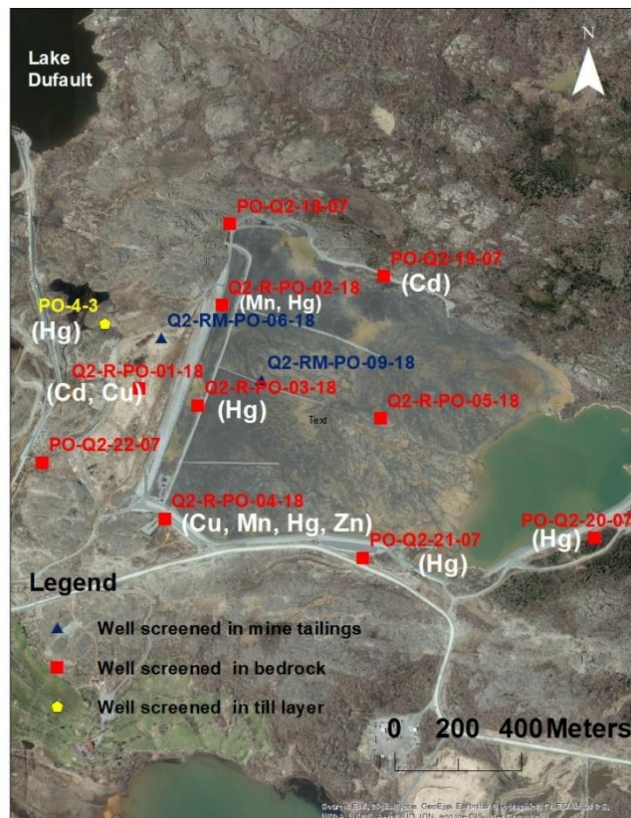
Figure 2 Piper Diagram.

Figure 3: Measured exceedances of comparison criteria for the analysed parameters in fall 2019.

Scientific outcomes

Ultimately, this project will allow for a quantitative evaluation of the hydrogeochemical exchanges between the tailings pond to the surrounding bedrock aquifer. The simulations will allow for evaluating and optimizing reclamation plans aimed at minimizing the risks associated with the migration of trace elements towards potential receptors.

Acknowledgements

References

CEAEQ (2008)., juillet 2008. Guide d'échantillonnage à des fins d'analyses environnementales : Cahier 1 – Généralités, Centre d'expertise en analyse environnementale du Québec, Ministère du Développement durable, de l'Environnement et des Parcs du Québec, 58 p., 3 annexes.

MELCC (2019)., Guide d'intervention- Protection des sols et réhabilitation des terrains contaminés. Ministère de l'Environnement et de la Lutte contre les changements climatiques.

MERN et MELCC (2017)., Guide de préparation du plan de réaménagement et de restauration des sites miniers au Québec, Ministère de l'Énergie et des Ressources naturelles et le ministère de l'Environnement et de la Lutte contre les changements climatiques.

Rouleau, A., Guha, J., Archambault, G., et Benlahcen, A., (1999). An overview of the hydrogeology of the precambian basement in Quebec and related mining problems. Hydrogéologie, n 4, 1999, pp.23-32. 4 fig. 1 tabl.

US EPA (1996)., EPA540/S-95/504 Low-Flow (Minimal Drawdown) Ground-Water Sampling Procedures. ONLINE. U.S. Environmental Protection Agency.Office of Research and Development & Office of Solid Waste and Emergency Response.

WSP (2019)., Modélisation Hydrogéologique. Parc à résidus actif Quémont 2, Rouyn-Noranda (Québec). Rapport produit pour Glencore Canada Corporation. 96 pages et annexes.

WSP (2019)., Plan de restauration-Sites. Mise à jour 2019. Rapport produit pour Glencore Canada Corporation-Fonderie Horne. 103 Pages et annexes.